

SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT WE, Yasushi Sugaya, a citizen of Japan residing at c/o FUJITSU LIMITED, 1-1, Kamikodanaka 4-chome, Nakahara-ku, Kawasaki-shi, Kanagawa, 211 Japan, Miki Takeda, a citizen of Japan residing at c/o FUJITSU LIMITED, 1-1, Kamikodanaka 4-chome, Nakahara-ku, Kawasaki-shi, Kanagawa, 211 Japan, Susumu Kinoshita, a citizen of Japan residing at c/o FUJITSU LIMITED, 1-1, Kamikodanaka 4-chome, Nakahara-ku, Kawasaki-shi, Kanagawa, 211 Japan and Terumi Chikama, a citizen of Japan residing at c/o FUJITSU LIMITED, 1-1, Kamikodanaka 4-chome, Nakahara-ku, Kawasaki-shi, Kanagawa, 211 Japan have invented certain new and useful improvements in

MULTI-WAVELENGTH LIGHT AMPLIFIER

of which the following is a specification : -

1 TITLE OF THE INVENTION

 MULTI-WAVELENGTH LIGHT AMPLIFIER

BACKGROUND OF THE INVENTION

5 1. Field of the Invention

 The present invention generally relates to a
light amplifier for a wavelength division multiplexed
(WDM) optical transmission system, and more
particularly to a light amplifier having a two-stage
10 configuration which eliminates a wavelength-dependence
of the gain of the light amplifier.

 Recently, an optical communications network
has increasingly been used in practice. Nowadays, it
is required that the optical communications network
15 cope with multi-media networking. A WDM system is
more attractive, particularly in terms of an increase
in the transmission capacity. In order to realize the
WDM system, it is necessary to use a multi-wavelength
light amplifier capable of amplifying a wavelength
20 division multiplexed signal. It is required that such
a multi-wavelength light amplifier does not have
wavelength-dependence of the gain, which is further
required not to be changed due to a variation in the
power of the input light.

25 A light amplifier is known which has an
optical fiber doped with a rare-earth element and
directly amplifies the input light. There has been
some activity in the development of a multi-wavelength
light amplifier which amplifies a wavelength division
30 multiplexed light signal including signal components
having different wavelengths (channels).

 However, normally, the rare-earth-element
doped fiber amplifier has a very narrow range in which
the gain thereof does not have the wavelength-
35 dependence. In this regard, nowadays, there is no
available light amplifier which can practically be
used for the WDM system. That is, there is no

1 available light amplifier which does not have
wavelength-dependence of the gain, which is not
changed due to a variation in the power of the input
light. Particularly, the wavelength-dependence of the
5 gain, which takes place when the input power changes,
deteriorates the signal-to-noise ratio with respect to
a particular signal. This prevents the multi-
wavelength light amplifier from being used in
practice.

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SUMMARY OF THE INVENTION

It is a general object of the present
invention to provide a multi-wavelength light
amplifier in which the above disadvantages are
15 eliminated.

A more specific object of the present
invention is to provide a multi-wavelength light
amplifier which does not have wavelength-dependence of
the gain, which is not changed due to a variation in
20 the power of the input light.

The above objects of the present invention
are achieved by a multi-wavelength light amplifier
comprising: a first-stage light amplifier which has a
first light amplifying optical fiber amplifying a
25 light input; a second-stage light amplifier which has
a second light amplifying optical fiber amplifying a
first light output from the first-stage light
amplifier; and an optical system which maintains a
second light output of the second-stage light
30 amplifier at a constant power level. The first-stage
and second-stage light amplifiers have different gain
vs wavelength characteristics so that the multi-
wavelength light amplifier has no wavelength-
dependence of a gain.

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The above multi-wavelength light amplifier
may be configured as follows. The first-stage light
amplifier comprises a first pump source which pumps

- 1 the first light amplifying optical fiber so as to have
a first gain vs wavelength characteristic in which as
a wavelength of light to be amplified becomes shorter,
a gain of the first-stage light amplifier becomes
5 higher. The second-stage light amplifier comprises a
second pump source which pumps the second light
amplifying optical fiber so as to have a second gain
vs wavelength characteristic in which as a wavelength
of light to be amplified becomes longer, a gain of the
10 first-stage light amplifier becomes higher.

The above multi-wavelength light amplifier
may be configured as follows. The first-stage light
amplifier comprises a first pump source which pumps
the first light amplifying optical fiber so as to have
15 a first gain vs wavelength characteristic having a
first linear gain slope. The second-stage light
amplifier comprises a second pump source which pumps
the second light amplifying optical fiber so as to
have a second gain vs wavelength characteristic having
20 a second linear gain slope. A combination of the
first and second linear gain slopes results in a flat
gain vs wavelength characteristic of the multi-
wavelength light amplifier.

- The above multi-wavelength light amplifier
25 may further comprise an optical filter which
emphasizes the gain vs wavelength characteristic of
the first-stage light amplifier.

The above multi-wavelength light amplifier
may further comprise an optical filter which
30 compensates for a difference between the gain vs
wavelength characteristics of the first-stage light
amplifier and the second-stage light amplifier.

- The above multi-wavelength light amplifier
may be configured as follows. The optical filter is
35 provided so as to follow the first-stage light
amplifier. The first-stage light amplifier comprises
a first pump source which pumps the first light

- 1 amplifying optical fiber so as to have a first gain vs
wavelength characteristic having a first linear gain
slope. The second-stage light amplifier comprises a
second pump source which pumps the second light
5 amplifying optical fiber so as to have a second gain
vs wavelength characteristic having a second linear
gain slope. The optical filter emphasizes the first
linear gain slope to provide an emphasized first
10 linear gain slope. A combination of the emphasized
first linear slope and the second linear gain slope
results in a flat gain vs wavelength characteristic of
the multi-wavelength light amplifier.

 The above multi-wavelength light amplifier
may be configured as follows. The optical filter is
15 provided so as to follow the first-stage light
amplifier. The first-stage light amplifier comprises
a first pump source which pumps the first light
amplifying optical fiber so as to have a first gain vs
wavelength characteristic having a first linear gain
20 slope. The second-stage light amplifier comprises a
second pump source which pumps the second light
amplifying optical fiber so as to have a second gain
vs wavelength characteristic having a second linear
gain slope. The optical filter compensates for the
25 difference between the first and second linear gain
slopes so that a flat gain vs wavelength
characteristic of the multi-wavelength light amplifier
can be obtained.

 The above multi-wavelength light amplifier
30 may be configured as follows. The first-stage light
amplifier has a first AGC (automatic gain control)
system so that a ratio of the input light and the
first light output is constant. The second-stage
light amplifier has a second AGC system so that a
35 ratio of the first light output and the second light
output is constant.

 The above multi-wavelength light amplifier

- 1 may be configured as follows. The first-stage light
amplifier has an AGC (automatic gain control) system
so that a ratio of the input light and the first light
output is constant. The second-stage light amplifier
5 has an automatic power control (APC) system so that
the second light amplifying optical fiber is pumped at
a predetermined constant power level.

- The above multi-wavelength light amplifier
may be configured as follows. The first-stage light
10 amplifier has an AGC (automatic gain control) system
so that a ratio of the input light and the first light
output is constant. The second-stage light amplifier
has an automatic level control (ALC) system so that
the second light output is maintained at a
15 predetermined constant power level.

- The above multi-wavelength light amplifier
may be configured as follows. The first AGC system
comprises first means for detecting a first level of
the light input and a second level of the first light
20 output and pumping the first light amplifying optical
fiber so that a ratio of the first and second levels
is maintained at a first predetermined constant value.
The second AGC system comprises second means for
detecting a third level of the first light output and
25 a fourth level of the second light output and pumping
the second light amplifying optical fiber so that a
ratio of the third and fourth levels is maintained at
a second predetermined constant value.

- The above multi-wavelength light amplifier
30 may be configured as follows. The first-stage light
amplifier has a first AGC (automatic gain control)
system which detects a first amplified spontaneous
emission of the first light amplifying optical fiber
and pumps the first light amplifying optical fiber so
35 that the first amplified spontaneous emission is
maintained at a first predetermined constant level.
The second-stage light amplifier has a second AGC

- 1 system which detects a second amplified spontaneous emission of the second light amplifying optical fiber and pumps the second light amplifying optical fiber so that the second amplified spontaneous emission is
5 maintained at a second predetermined constant level.

The above multi-wavelength light amplifier may be configured as follows. The first-stage light amplifier has a first-AGC (automatic gain control) system which detects a first pump light propagated
10 through the first light amplifying optical fiber and pumps the first light amplifying optical fiber so that the first pump light is maintained at a first predetermined constant level., The second-stage light amplifier has a second AGC system which detects a
15 second pump light propagated through the second light amplifying optical fiber and pumps the second light amplifying optical fiber so that the second pump light is maintained at a second predetermined constant level.

- 20 The above multi-wavelength light amplifier may be configured as follows. The first-stage light amplifier comprises a first pump source which pumps the first light amplifying optical fiber through a first coupler so as to have a first gain vs wavelength
25 characteristic in which as a wavelength of light to be amplified becomes shorter, a gain of the first-stage light amplifier becomes higher. The second-stage light amplifier comprises a second pump source which pumps the second light amplifying optical fiber
30 through a second coupler so as to have a second gain vs wavelength characteristic in which as a wavelength of light to be amplified becomes longer, a gain of the first-stage light amplifier becomes higher. At least one of the first and second couplers has a
35 characteristic which emphasizes one of the gain vs wavelength characteristics of the first-stage and second-stage light amplifiers.

1 The above multi-wavelength light amplifier
may be configured as follows. The optical system
which maintains the second light output of the second-
stage light amplifier at a constant power level
5 comprises a variable attenuator which is provided
between the first-stage light amplifier and the
second-stage light amplifier and attenuates the first
output signal on the basis of the power level of the
second light output.

10 The above multi-wavelength light amplifier
may be configured as follows. The optical system
which maintains the second light output of the second-
stage light amplifier at a constant power level
comprises a variable attenuator which is provided so
15 as to follow the second-stage light amplifier and
attenuates the second output signal on the basis of
the power level of an attenuated second light output
from the variable attenuator.

 The above multi-wavelength light amplifier
20 may be configured as follows. The optical system
which maintains the second light output of the second-
stage light amplifier at a constant power level
comprises a variable attenuator which is provided
between the first-stage light amplifier and the
25 second-stage light amplifier and attenuates the first
output signal on the basis of the power level of an
attenuated first light output from the variable
attenuator.

 The above multi-wavelength light amplifier
30 may further comprise a rejection filter which is
provided between the first-stage light amplifier and
the second-stage light amplifier and prevents a pump
light which pumps the first light amplifying optical
fiber from being transmitted to the second-stage light
35 amplifier.

BRIEF DESCRIPTION OF THE DRAWINGS

1 Other objects, features and advantages of
the present invention will become more apparent from
the following detailed description when read in,
conjunction with the accompanying drawings, in which:

5 Fig. 1 is a block diagram of a multi-
wavelength light amplifier according to a first
embodiment of the present invention;

Fig. 2 is a diagram showing a principle of a
multi-wavelength light amplifier according to a second
10 embodiment of the present invention;

Fig. 3 is a block diagram of a multi-
wavelength light amplifier according to a third
embodiment of the present invention;

Fig. 4 is a diagram showing a principle of
the multi-wavelength light amplifier according to the
15 third embodiment of the present invention;

Fig. 5 is a block diagram of a multi-
wavelength light amplifier according to a fourth
embodiment of the present invention;

20 Fig. 6 is a diagram showing a principle of
the multi-wavelength light amplifier according to the
fourth embodiment of the present invention;

Figs. 7A and 7B are diagrams showing a
principle of a multi-wavelength light amplifier
25 according to a fifth embodiment of the present
invention;

Fig. 8 is a block diagram of a multi-
wavelength light amplifier according to a seventh
embodiment of the present invention;

30 Fig. 9 is a block diagram of a multi-
wavelength light amplifier according to an eighth
embodiment of the present invention;

Fig. 10 is a block diagram of a multi-
wavelength light amplifier according to a ninth
35 embodiment of the present invention;

Fig. 11 is a block diagram of a multi-
wavelength light amplifier according to a tenth

1 embodiment of the present invention;

Fig. 12 is a block diagram of a multi-wavelength light amplifier according to an eleventh embodiment of the present invention;

5 Fig. 13 is a block diagram of a multi-wavelength light amplifier according to a twelfth embodiment of the present invention;

Fig. 14 is a block diagram of a multi-wavelength light amplifier according to a thirteenth embodiment of the present invention; and

10 Fig. 15 is a block diagram of a multi-wavelength light amplifier according to a fourteenth embodiment of the present invention.

15 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 1 is a block diagram of a multi-wavelength light amplifier according to a first embodiment of the present invention. The amplifier shown in Fig. 1 includes a first-stage (front-stage) light amplifier 1 and a second-stage (rear-stage) light amplifier 2. A variable attenuator (ATT) 11 is provided between the first and second amplifiers 1 and 2. The variable attenuator 11 is controlled by an automatic level control (ALC) circuit 14, which is controlled by a photodetector 13 such as a photodiode. The photodiode 13 receives split light from a beam splitting coupler 12, which follows the second-stage amplifier 2. An optical system having a feedback loop is formed by the light splitting coupler 12, the photodiode 13, the ALC circuit 14 and the variable attenuator 11.

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The first-stage amplifier 1 includes a first-stage light input monitor made up of a beam splitting coupler 3₁ and a photodiode 4₁, and a first-stage light output monitor made up of a beam splitting coupler 3₂ and a photodiode 4₂. Further, the first-stage amplifier 1 includes a light amplifying optical

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1 fiber 7 such as a rare-earth-element doped optical
fiber and an exciting-light source (hereinafter
referred to as a pump source: PS) 9₁, which is
controlled by an automatic gain control (AGC) circuit
5 6₁ provided in the first-stage amplifier 1. An AGC
system including the AGC circuit 6₁ and the above
input and output monitors performs an AGC control of
the pump source 9₁ so that the ratio of the light
input power level detected by the light input monitor
10 and the light output power level detected by the light
output monitor can be maintained at a constant value.
The above ratio corresponds to the gain of the first-
stage amplifier 1.

The second-stage amplifier 2 includes a
15 second-stage light input monitor made up of a beam
splitting coupler 3₃ and a photodiode 4₃, and a
second-stage light output monitor made up of a beam
splitting coupler 3₄ and a photodiode 4₄. Further,
the second-stage amplifier 2 includes a light
20 amplifying optical fiber 8 such as rare-earth-element
doped optical fiber, and a pump source 9₂, which is
controlled by an AGC circuit 6₂ provided in the
second-stage amplifier 2. An AGC system including the
AGC circuit 6₂ and the above input and output monitors
25 performs a AGC operation of the pump source 9₂ so that
the ratio of the light input power level detected by
the light input monitor and the light output power
level detected by the light output monitor can be
maintained at a constant value.

30 The combination of the first-stage amplifier
1 and the second-stage amplifier 2 functions to cancel
the difference between the gain of the amplifier 1 and
the gain of the amplifier 2 in each of the wavelengths
of the multiplexed signal. That is, the amplifiers 1
35 and 2 have different gain vs. wavelength
characteristics (which may be simply referred to as
gain characteristics), which can be compensated by the

1 combination of the amplifiers 1 and 2. As a result,
the entire multi-wavelength light amplifier has a flat
gain vs wavelength characteristic.

It will now be assumed that $G_{0,1}$ denotes an
5 AGC control setting level which causes the amplifier 1
to have a flat gain vs wavelength characteristic in
which the output spectra at the respective wavelengths
of the multiplexed signal have a constant peak value.
Similarly, $G_{0,2}$ is denoted as an AGC control setting
10 level which causes the amplifier 2 to have a flat gain
vs wavelength characteristic in which the output
spectra at the respective wavelengths of the
multiplexed signal have a constant peak value. In
order to achieve the above cancellation, the practical
15 AGC control setting levels G_1 and G_2 of the amplifiers
1 and 2 are set so that $G_1 \geq G_{0,1}$ and $G_2 \leq G_{0,2}$. In
this case, as will be described later with reference
to Fig. 2, the amplifiers 1 and 2 can have gain vs
wavelength characteristics that can be compensated by
20 the combination thereof. For example, the gain of the
amplifier 1 at a wavelength is large, while the gain
of the amplifier 2 at the same wavelength as described
above is small. Hence, the total gain obtained by the
amplifiers 1 and 2 can be maintained at a constant
25 (flat) level. By combining the two amplifiers
together as described above, it is possible for the
multi-wavelength light amplifier to have no waveform-
dependence of the gain thereof.

The above waveform-dependence of the gain
30 can be maintained at a constant level irrespective of
a variation in the input power by means of the
feedback loop including the light splitting coupler
12, the photodiode 13, the ALC circuit 14 and the
variable attenuator 11. The split light from the beam
35 splitting coupler 12 is applied to the photodiode 13,
which generates an electric signal corresponding to
the light level. The above electric signal is applied

1 to the variable attenuator 11, and the amount of
attenuation caused therein is varied on the basis of
the light level detected by the photodiode 13. In
this manner, the light output level of the second-
5 stage amplifier 2 can be maintained at a constant
level. The variable attenuator 11 may be formed by
using a Faraday rotator or the electro-optical effect
of a lithium niobate (LiNbO_3) crystal.

The amplifiers 1 and 2 are pumped forward by
10 the pump sources 9_1 and 9_2 . Alternatively, it is
possible to pump the amplifiers 1 and 2 backward. It
is also possible to pump the amplifiers 1 and 2
forward and backward.

The light amplifier shown in Fig. 1 is
15 capable of amplifying all the wavelengths to be
multiplexed so that the light amplifier does not have
the wavelength-dependence of the gain, which is not
changed due to a variation in the power of the input
light. If some wavelengths are not used or only some
20 wavelengths are used, a filter (not shown) having a
corresponding wavelength characteristic may be placed
before the photodiode 4_1 (4_3) or 4_2 (4_4) of the first-
stage (second-stage) amplifier 1 (2) or both thereof.

Fig. 2 is a diagram of the operation of a
25 multi-wavelength light amplifier according to a second
embodiment of the present invention. The second
embodiment has the same configuration as shown in Fig.
1. According to the second embodiment of the present
invention, the optical fibers 7 and 8 are erbium-doped
30 (Er-doped) optical fibers, which are examples of rare-
earth-element doped optical fibers. Normally, alumina
(Al_2O_3) is added to the Er-doped optical fibers at a
high concentration level. In this regard, the Er-
doped optical fiber may be called a co-doped optical
35 fiber. The Er-doped optical fiber has a substantially
linear gain vs wavelength characteristic in an
amplifying band about 1550 nm, as shown in Fig. 2.

1 Part (a) of Fig. 2 shows a gain vs
wavelength characteristic obtained in the amplifying
band about 1550 nm when the exciting rate is
relatively high, and part (b) of Fig. 2 shows a gain
5 vs wavelength characteristic obtained in the
amplifying band about 1550 nm when the exciting rate
is relative low. The characteristics shown in parts
(a) and (b) of Fig. 2 are due to the characteristics
of absorption/emission of Er ions in the Er-doped
10 optical fiber with alumina added thereto at a high
concentration level. The horizontal axes of the parts
(a), (b) and (c) of Fig. 2 denote the wavelength, and
the vertical axes thereof denote the gain of the Er-
doped optical fiber.

15 As shown in part (a) of Fig. 2, in the
amplifying band about 1550 nm, the fiber has a
relatively high gain on the short-wavelength side, and
a relatively low gain on the long-wavelength side. In
other words, as the wavelength becomes shorter, the
20 gain becomes higher. As shown in part (b) of Fig. 2,
in the amplifying band about 1550 nm, the fiber has a
relatively high gain on the long-wavelength side, and
a relatively low gain on the short-wavelength side.
In other words, as the wavelength becomes longer, the
25 gain becomes higher.

 According to the second embodiment of the
present invention, the Er-doped fiber 7 of the first
amplifier 1 is long enough to increase the exciting
rate and obtain the characteristic shown in part (a)
30 of Fig. 2. The Er-doped fiber 8 of the second
amplifier 1 is short enough to decrease the exciting
rate and obtain the characteristic shown in part (b)
of Fig. 2. Generally, when the pumping of the Er-
doped fiber is increased, the gain vs wavelength
35 characteristic is changed from part (b) of Fig. 2 to
part (a) through part (c).

 The linear gain slope characteristic of the

- 1 first-stage amplifier 1 and that of the gain
characteristic of the second-stage amplifier 2 are
canceled by the combination of the amplifiers 1, and 2,
so that a flat gain vs wavelength characteristic (a
5 spectrum characteristic having a constant gain) as
shown in part (c) of Fig. 2 can be obtained.

It is preferable for the first-stage
amplifier 1 to be a low noise figure. In this regard,
the Er-doped fiber 7 of the first-stage amplifier is
10 used at a relatively high exciting rate. In this
case, the exciting efficiency is not high. The Er-
doped fiber 8 is used at a relatively low exciting
rate. Hence, it is possible to improve the exciting
efficiency of the second-stage amplifier 1. This
15 contributes to reducing energy consumed in the second-
stage amplifier 2.

The following data has been obtained through
an experiment in which the multi-wavelength light
amplifier was actually produced. The light amplifier
20 produced in the experiment was designed to amplify
four wavelengths (1548 nm, 1551 nm, 1554 nm, 1557 nm).
The light input level used in the experiment was
selected so as to fall within the range of -25 dBm
through -15 dBm. The gain and the gain tilt of the
25 first-stage amplifier 1 were respectively set to 20 dB
and 1.5 dB at a maximum power of the exciting light
equal to -160 mW (980 nm). The second-stage amplifier
2 was adjusted so as to produce, for each channel, the
light output equal to +7 dBm at a maximum power of the
30 exciting light equal to -100 mW (1480 nm). In this
case, the multi-wavelength light amplifier has a
maximum noise figure of 5.6 dB and a maximum gain tilt
of 0.2 dB.

Fig. 3 is a block diagram of a multi-
35 wavelength light amplifier according to a third
embodiment of the present invention. In Fig. 3, parts
that are the same as those shown in Fig. 1 are

1 indicated by the same reference numbers. The light
amplifier shown in Fig. 3 has an optical filter 15 for
compensating for a wavelength characteristic, as will
be described below. The optical filter 15 is provided
5 between the variable attenuator 11 and the input side
of the second-stage amplifier 2.

Fig. 4 is a diagram showing the operation of
the light amplifier shown in Fig. 3. More
particularly, part (a) of Fig. 4 shows a gain vs
10 wavelength characteristic of the first-stage amplifier
1 shown in Fig. 3; and part (b) thereof shows a gain
vs wavelength characteristic obtained by the
combination of the first-stage amplifier 1 and the
optical filter 15. Part (c) of Fig. 4 shows a gain vs
15 wavelength characteristic of the second-stage
amplifier 2 shown in Fig. 4, and part (d) shows a
total gain vs wavelength characteristic of the whole
light amplifier shown in Fig. 3.

The configuration of the first-stage
20 amplifier 1 shown in Fig. 3 is the same as that of the
amplifier 1 shown in Fig. 1. The configuration of the
second-stage amplifier 2 shown in Fig. 3 is the same
as that of the amplifier 2 shown in Fig. 1.

The optical filter 15 emphasizes the gain vs
25 wavelength characteristic of the first-stage amplifier
1. As shown in parts (a) and (b) of Fig. 4, the gain
for the short wavelengths is particularly emphasized.
In other words, the linear gain slope of the
characteristic shown in part (a) of Fig. 4 is
30 increased by the optical filter 15. The
characteristic of the second-stage amplifier 2 shown
in part (c) of Fig. 4 compensates for the
characteristic shown in part (b) thereof, so that the
flat gain characteristic shown in part (d) of Fig. 4
35 can be finally obtained.

It will be noted that the exciting rate
necessary to obtain the characteristic shown in part

1 (c) of Fig. 4 is lower than that necessary to obtain
the characteristic shown in part (b) of Fig. 2. In
other words, the exciting efficiency of the
characteristic shown in part (c) of Fig. 4 is higher
5 than that of the characteristic shown in part (b) of
Fig. 2. Hence, the second-stage amplifier 2 shown in
Fig. 3 consumes a smaller amount of energy than that
shown in Fig. 1. In other words, if the second-stage
amplifier 2 shown in Fig. 3 consumes the same amount
10 of energy as that shown in Fig. 1, the multi-
wavelength light amplifier shown in Fig. 3 can output
a larger amount of power than that shown in Fig. 1.

Since the first-stage amplifier 1 has the
characteristic shown in part (a) of Fig. 4, it is a
low noise figure. The characteristic of the first-
stage amplifier 1 is emphasized by the optical filter
15, and the exciting efficiency thereof may be
improved.

The variable attenuator 11 shown in Fig. 3
20 is controlled in the same manner as that shown in Fig.
1 as has been described previously. In short, the
variable attenuator 11 maintains the level of the
output light of the second-stage amplifier 1 at the
predetermined constant level.

25 Fig. 5 is a block diagram of a multi-
wavelength light amplifier according to a fourth
embodiment of the present invention. In Fig. 5, parts
that are the same as those shown in the previously
described figures are given the same reference
30 numbers. The configuration shown in Fig. 5 differs
from that shown in Fig. 3 in that the optical filter
15 shown in Fig. 5 is provided between the output side
of the second-stage amplifier 2 and the beam splitting
coupler 12.

35 Fig. 6 is a diagram showing the operation of
the light amplifier shown in Fig. 5. More
particularly, part (a) of Fig. 6 shows a gain vs

1 wavelength characteristic of the first-stage amplifier
1 shown in Fig. 5, and part (b) thereof shows a gain
vs wavelength characteristic of the second-stage
amplifier 2 shown in Fig. 5. Part (c) of Fig. 5 is a
5 gain vs wavelength characteristic obtained by the
combination of the first-stage amplifier 1 and the
second-stage amplifier 2. Part (d) of Fig. 6 shows a
total gain vs wavelength characteristic of the whole
light amplifier shown in Fig. 5.

10 The configuration of the first-stage
amplifier 1 shown in Fig. 5 is the same as that of the
amplifier 1 shown in Figs. 1 and 3. The configuration
of the second-stage amplifier 2 shown in Fig. 5 is the
same as that of the amplifier 2 shown in Figs. 1 and
15 3.

The optical filter 15 has a gain vs
wavelength characteristic which compensates for that
shown in part (b) of Fig. 2. As shown in parts (a)
and (b) of Fig. 6, the characteristic of the second-
20 stage amplifier 2 is pumped so as to have an
emphasized gain vs wavelength characteristic, as
compared to that of the first-stage amplifier 1. In
the emphasized characteristic, the gain for the long
wavelengths is particularly emphasized. In other
25 words, the linear gain slope of the characteristic
shown in part (b) of Fig. 6 is greater than that shown
in part (a) thereof although the linear gain slopes
shown in parts (a) and (b) thereof are oriented in
different directions. The combination of the first-
30 stage amplifier 1 and the second-stage amplifier 2
results in the characteristic shown in part (c) of
Fig. 6. It is not required that the first-stage
amplifier 1 and the second-stage amplifier 2 have
characteristics of such a difference which can be
35 completely canceled by the combination thereof.

The optical filter 15 shown in Fig. 5 has a
gain vs wavelength characteristic which compensates

- 1 for the characteristic shown in part (c) of Fig. 6.
Thus, the total characteristic is as shown in part (d)
of Fig. 6.

- It will be noted that the exciting rate
5 necessary to obtain the characteristic shown in part
(b) of Fig. 6 is lower than that necessary to obtain
the characteristic shown in part (b) of Fig. 2. In
other words, the exciting efficiency of the
characteristic shown in part (b) of Fig. 6 is higher
10 than that of the characteristic shown in part (b) of
Fig. 2. Hence, the second-stage amplifier 2 shown in
Fig. 5 consumes a smaller amount of energy than that
shown in Fig. 1. In other words, if the second-stage
amplifier 2 shown in Fig. 5 consumes the same amount
15 of energy as that shown in Fig. 1, the multi-
wavelength light amplifier shown in Fig. 5 can output
a larger amount of power than that shown in Fig. 1.

- The variable attenuator 11 shown in Fig. 5
is controlled in the same manner as that shown in Fig.
20 1 as has been described previously. In short, the
variable attenuator 11 shown in Fig. 5 maintains the
level of the output light of the second-stage
amplifier 1 at the predetermined constant level.

- The optical filter 15 used in Fig. 3 or Fig.
25 5 may be a conventional coupler of a melting
attachment type. By adjusting the wavelength period
of the coupler, it is possible to use the coupler as a
gain tilting filter. For example, the optical filter
15 shown in Fig. 5 has a gain tilt equal to
30 approximately 3 dB in order to obtain the flat gain
characteristic shown in part (d) of Fig. 6.

- A description will now be given of a multi-
wavelength light amplifier according to a fifth
embodiment of the present invention. This embodiment
is intended to obtain the same function as the
35 configuration shown in Fig. 3 without the optical
filter 15 shown therein. In other words, the light

1 amplifier according to the fifth embodiment is configured as shown in Fig. 1, nevertheless it has the function of the light amplifier shown in Fig. 3.

According to the fifth embodiment of the
5 present invention, the beam splitting coupler 5_2 is replaced by a beam splitting coupler 21 shown in Fig. 7A, which has a transparent rate vs wavelength characteristic as shown in Fig. 7B. In Fig. 7A, a pump source 22 which corresponds to the pump source 9_2
10 is coupled to the beam splitting coupler 21. In Fig. 7B, symbol λ_p denotes the wavelength of the pump light emitted from the source 22. Symbol λ_s denotes the central wavelength of the multiplexed light signal. Symbols λ_{s1} and λ_{sn} are wavelengths which define the
15 band of the multiplexed light signal. A solid line shown in Fig. 7B denotes a characteristic used for communications. Two dot lines are obtained by shifting the solid line. As indicated by the solid line, the beam splitting coupler 21 functions to pass
20 the multiplexed signal light and prevent the pump light in the forward direction.

By shifting the solid line toward the short-wavelength side as indicated by character A in Fig. 7B, the characteristic curve of the transparent rate
25 has a slope in the band defined by the wavelengths λ_{s1} and λ_{sn} . In this case, the highest transparent rate can be obtained at the shortest wavelength λ_{s1} , and the lowest transparent rate can be obtained at the longest wavelength λ_{sn} . This characteristic
30 corresponds to the characteristic of the optical filter 15 used in the configuration shown in Fig. 3. With the above configuration, the multi-wavelength light amplifier according to the fifth embodiment of the present invention has the same advantages as those
35 of the light amplifier shown in Fig. 3.

The beam splitting coupler 21 can be applied to the first-stage amplifier 1 instead of the second-

1 stage amplifier 2. In this case, the Er-doped optical
fiber 7 of the first-stage amplifier 1 is pumped
backward by the pump source 22 because the optical
filter 15 shown in Fig. 3 is placed on the output side
5 of the Er-doped optical fiber 7.

A description will now be given of a multi-
wavelength light amplifier according to a sixth
embodiment of the present invention. This embodiment
is intended to obtain the same function as the
10 configuration shown in Fig. 5 without the optical
filter 15 shown therein. In other words, the light
amplifier according to the sixth embodiment is
configured as shown in Fig. 1, nevertheless it has the
function of the light amplifier shown in Fig. 5.

15 In the sixth embodiment of the present
invention, the pump source 9₂ shown in Fig. 1 is
replaced by the pump source 22 shown in Fig. 7A having
the transparent rate characteristic indicated by B
shown in Fig. 7B in such a way that the Er-doped
20 optical fiber 8 is pumped backward by the pump source
22. This is because the optical filter 15 shown in
Fig. 5 is placed on the output side of the Er-doped
optical fiber 8 shown in Fig. 5.

By shifting the solid line shown in Fig. 7B
25 toward the long-wavelength side as indicated by
character B, the characteristic curve of the
transparent rate has a slope in the band defined by
the wavelengths λ_{s1} and λ_{sn} . In this case, the
highest transparent rate can be obtained at the
30 longest wavelength λ_{sn} , and the lowest transparent
rate can be obtained at the shortest wavelength λ_{s1} .
This characteristic corresponds to the characteristic
of the optical filter 15 used in the configuration
shown in Fig. 5. With the above configuration, the
35 multi-wavelength light amplifier according to the
sixth embodiment of the present invention has the same
advantages as those of the light amplifier shown in

1 Fig. 5.

It will be noted that the above-mentioned third through sixth embodiments of the present invention may be combined appropriately.

5 Fig. 8 is a multi-wavelength light amplifier according to a seventh embodiment of the present invention. In Fig. 8, parts that are the same as those shown in the previously described figures are given the same reference numbers. The light amplifier
10 shown in Fig. 8 has a second-stage light amplifier 2A having a configuration different from the above-mentioned second-stage light amplifier 2.

More particularly, the second-stage amplifier 2A has an automatic power control (APC) circuit 10. The APC circuit 10 monitors and controls
15 the pump light emitted from the pump source 9₂, so that the pump light can be emitted at a predetermined constant level. As has been described previously, the variable attenuator 11 functions to maintain the
20 amplified light output by the second-stage amplifier 2 at the predetermined constant level. Hence, even by the automatic power control of the pump light directed to maintaining the pump light at the constant level, it is possible to maintain the output light of the
25 second-stage amplifier 2A at the predetermined constant level even if the power of the light input signal fluctuates.

The first-stage amplifier 1 shown in Fig. 8 has a gain vs wavelength characteristic as shown in
30 part (a) of Fig. 2, and the second-stage amplifier 2A shown in Fig. 8 has a gain vs wavelength characteristic as shown in part (b) of Fig. 2.

The second-stage amplifier 2A does not need the couplers 3₃ and 3₄, and the photodiodes 4₃ and 4₄.
35 Hence, the second-stage amplifier 2A is simpler than the second-stage amplifier 2, so that down-sizing of the light amplifier can be facilitated.

1 Fig. 9 is a block diagram of a multi-
wavelength light amplifier according to an eighth
embodiment of the present invention. In Fig. 9, parts
that are the same as those shown in the previously
5 described figures are given the same reference
numbers. The configuration shown in Fig. 9 differs
from the configuration shown in Fig. 1 in that the
variable attenuator 11 shown in Fig. 9 is provided on
the output side of the second-stage amplifier 2.
10 Thus, the variable attenuator 11 attenuates the output
light signal of the second-stage amplifier 2 so that
it can be maintained at the predetermined constant
level.

It will be noted that in the configuration
15 shown in Fig. 1, the attenuated light signal from the
variable attenuator 11 is amplified by the second-
stage amplifier 2. On the other hand, in the
configuration shown in Fig. 9, the variable attenuator
11 attenuates the light output signal of the second-
20 stage amplifier 2. Hence, the second-stage amplifier
2 shown in Fig. 9 needs a much larger amount of energy
of the pump light than that used in the configuration
shown in Fig. 1. However, except for the above, the
light amplifier shown in Fig. 9 has the same
25 advantages as the configuration shown in Fig. 1. For
example, the light amplifier shown in Fig. 9 has a low
noise figure because an increase in loss of the gain
does not occur between the first-stage amplifier 1 and
the second-stage amplifier 2.

30 It will be noted that the first-stage and
second-stage amplifiers 1 and 2 (2A) are not limited
to the previously described AGC (APC) circuits in
order to obtain the characteristics shown in Figs. 2,
4 and 6. It is possible to arbitrarily combine the
35 previously described AGC circuits. Further, it is
also possible to employ other AGC circuits or
equivalents thereof, which will be described below as

1 ninth through eleventh embodiments of the present
invention. It will be noted that the AGC circuit of
the first-stage circuit can be selected separately
from the AGC circuit of the second-stage circuit.

5 Fig. 10 is a block diagram of a multi-
wavelength light amplifier according to a ninth
embodiment of the present invention, wherein parts
that are the same as those shown in Fig. 1 are given
the same reference numbers. The light amplifier shown
10 in Fig. 10 has a first-stage amplifier 1B and a
second-stage amplifier 2B, which are different from
the amplifiers 1 and 2.

The first-stage amplifier 1B, which has a
gain vs wavelength characteristic as shown in part (a)
15 of Fig. 2, has a forward-direction photodiode 20_1 ,
which detects an amplified spontaneous emission (ASE)
leaking from the side surface of the Er-doped optical
fiber 7. The AGC circuit 6_1 is supplied with the
output signal of the photodiode 20_1 and controls the
20 pump power of the pump source 9_1 so that the amplified
spontaneous emission can be maintained at a
predetermined constant level. As a result of the AGC
control, the gain of the front-stage amplifier 1B can
be maintained at the predetermined constant value.

25 Similarly, the second-stage amplifier 2B,
which has a gain vs wavelength characteristic as shown
in part (b) of Fig. 2, has a forward-direction
photodiode 20_2 , which detects the amplified
spontaneous emission leaking from a side surface of
30 the Er-doped optical fiber 8. The AGC circuit 6_2 is
supplied with the output signal of the photodiode 20_2
and controls the pump power of the pump source 9_2 so
that the amplified spontaneous emission can be
maintained at a predetermined constant level. As a
35 result of the above AGC control, the gain of the
second-stage amplifier 2B can be maintained at the
predetermined constant level.

1 As has been described previously, the
variable attenuator 11 provided between the first-
stage amplifier 1B and the second-stage amplifier 2B
functions to maintain the light output level at the
5 predetermined constant level.

Fig. 11 is a block diagram of a multi-
wavelength light amplifier according to a tenth
embodiment of the present invention, in which parts
that are the same as those shown in the previously
10 described figures are given the same reference
numbers. The light amplifier shown in Fig. 11
includes a first-stage light amplifier 1C and a
second-stage light amplifier 2C.

The first-stage light amplifier 1C, which
15 has a gain vs wavelength characteristic as shown in
part (a) of Fig. 2, includes a WDM coupler 16₁ and a
photodiode 17₁. The WDM coupler 16₁ separates the
light in the 1530 nm band (ASE) from the light in the
1550 nm band (signal light). The above ASE travels
20 toward the input side of the Er-doped optical fiber 7.
(backward ASE). The photodiode 17₁ detects the
amplified spontaneous emission of the Er-doped optical
fiber 7. The AGC circuit 6₁ receives the output
signal of the photodiode 17₁ and controls the pump
25 power of the pump source 9₁ so that the backward ASE
can be maintained at a predetermined constant level.
As a result of the above AGC control, the gain of the
first-stage amplifier 1C can be maintained at the
predetermined constant level.

The second-stage light amplifier 2C, which
30 has a gain vs wavelength characteristic as shown in
part (b) of Fig. 2, includes a WDM coupler 16₂ and a
photodiode 17₂. The WDM coupler 16₂ separates the
light in the 1530 nm band (ASE) from the light in the
1550 nm band (signal light). The above ASE travels
35 toward the input side of the Er-doped optical fiber 8
(backward ASE). The photodiode 17₂ detects the

1 amplified spontaneous emission of the Er-doped optical
fiber 8. The AGC circuit 6₂ receives the output
signal of the photodiode 17₂ and controls the pump
power of the pump source 9₂ so that the backward ASE
5 can be maintained at a predetermined constant level.
As a result of the above AGC control, the gain of the
second-stage amplifier 2C can be maintained at the
predetermined constant level.

As has been described previously, the
10 variable attenuator 11 provided between the first-
stage amplifier 1C and the second-stage amplifier 2C
functions to maintain the light output level at the
predetermined constant level.

Fig. 12 is a block diagram of a multi-
15 wavelength light amplifier according to an eleventh
embodiment of the present invention, in which parts
that are the same as those shown in the previously
described figures are given the same reference
numbers. The light amplifier shown in Fig. 12
20 includes a first-stage light amplifier 1D and a
second-stage light amplifier 2D.

The first-stage light amplifier 1D, which
has a gain vs wavelength characteristic as shown in
part (a) of Fig. 2, includes a WDM coupler 5₃ and a
25 photodiode 18₁. The WDM-coupler 5₃ is provided on the
output side of the Er-doped optical fiber 7, and
separates the residual pump light (exciting light)
propagated through the fiber 7 from the signal light.
The residual pump light separated by the WDM coupler
30 5₃ is applied to the photodiode 18₁, which outputs a
corresponding electric signal to the AGC circuit 6₁.
Then, the AGC circuit 6₁ controls the pump power of
the pump source 9₁ on the basis of the detected
residual pump light so that the residual pump light
35 can be maintained at a predetermined constant level.
As a result of the above AGC control, the gain of the
first-stage amplifier 1D can be maintained at the

- 1 predetermined constant level.

The second-stage light amplifier 2D, which has a gain vs wavelength characteristic as shown in part (b) of Fig. 2, includes a WDM coupler 5₄ and a photodiode 18₂. The WDM coupler 5₄ is provided on the output side of the Er-doped optical fiber 8, and separates the residual pump light (exciting light) propagated through the fiber 8 from the signal light. The residual pump light separated by the WDM coupler 5₄ is applied to the photodiode 18₂, which outputs a corresponding electric signal to the AGC circuit 6₂. Then, the AGC circuit 6₂ controls the pump power of the pump source 9₂ on the basis of the detected residual pump light so that the residual pump light can be maintained at a predetermined constant level. As a result of the above AGC control, the gain of the second-stage amplifier 2D can be maintained at the predetermined constant level.

As has been described previously, the variable attenuator 11 provided between the first-stage amplifier 1D and the second-stage amplifier 2D functions to maintain the light output level at the predetermined constant level.

Fig. 13 is a block diagram of a multi-wavelength light amplifier according to a twelfth embodiment of the present invention, wherein parts that are the same as those shown in the previously described figures are given the same reference numbers. The light amplifier shown in Fig. 13 differs from that shown in Fig. 1 in that the beam splitting coupler 12 is provided between the variable attenuator 11 and the second-stage amplifier 2.

It is possible to maintain the light output of the second-stage amplifier 2 at the predetermined constant level by controlling the variable attenuator 11 on the basis of the attenuated light output so that the attenuated light output is maintained at a

1 predetermined constant level. In order to realize the
above feedback control, the photodiode 13 detects a
split component of the attenuated light output, and
the ALC circuit 14 controls the variable attenuator 11
5 in the above-described manner.

Fig. 14 is a block diagram of a multi-
wavelength light amplifier according to a thirteenth
embodiment of the present invention, in which parts
that are the same as those shown in the previously
10 described figures are given the same reference
numbers. The light amplifier shown in Fig. 14
corresponds to a modification of the light amplifier
shown in Fig. 13. The light amplifier shown in Fig.
14 has the first-stage light amplifier 1 and a second-
15 stage light amplifier 2E.

The second-stage light amplifier 2E, which
has a gain vs wavelength characteristic as shown in
part (b) of Fig. 2, includes a beam splitting coupler
3₄, the photodiode 4₄ and an ALC circuit 14₂. It will
20 be noted that the second-stage amplifier 2E is simpler
than the second-stage amplifier 2 shown in Fig. 13.
As has been described previously with reference to
Fig. 13, the attenuated light output is maintained at
the predetermined constant level. Hence, the
25 operation of the second-stage amplifier 2E receiving
the attenuated light output through the beam splitting
coupler 12 is equivalent to the AGC-controlled
operation of the second-stage amplifier. Hence, it is
possible to control the pump power of the pump source
30 9₂ by the automatic level control performed by the ALC
circuit 14₂.

Fig. 15 shows a multi-wavelength light
amplifier according to a fourteenth embodiment of the
present invention. This amplifier includes a
35 rejection filter 30 provided between the first-stage
amplifier 1 and the second-stage amplifier 2. The
rejection filter 30 prevents the pump light propagated

- 1 from the Er-doped optical fiber 7 from passing
therethrough, and improves the exciting efficiency of
the second-stage amplifier 2. The rejection filter 30
can be applied to the other embodiments of the present
5 invention in the same manner as shown in Fig. 15.

The above-described embodiments of the
present invention can be arbitrarily combined to
provide variations and modifications.

- 10 The present invention is not limited to the
specifically disclosed embodiments, and variations and
modifications may be made without departing from the
scope of the present invention.

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